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(19) (CA) **CANADIAN PATENT** (12)

(54) **Soil-Metal Arch Bridge on Reinforced Earth Abutments**

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ABSTRACT OF THE DISCLOSURE

Commonly known soil-metal structures are built in the form of buried arches or closed conduits with circular, elliptic or pipe arch configuration. They are used as bridges, underground shelters and underground storage. In the case of buried arches, concrete footings supported by undisturbed soil are used. If more headroom is required the arches are supported by reinforced-earth abutments. According to the invention the metal structure is tied to the surrounding soil, such as granular backfill by means of layers of horizontally placed flat bars (strips). In addition, the soil cover above the metal structure is reinforced by layers of horizontally placed flat bars (strips). In this manner, the contribution of the entire reinforced soil mass to the stability of the composite structure is assured.

5 This invention relates to reinforced soil-metal  
structures. More particularly, the present invention  
relates to a system of reinforced-soil-metal  
structures in which the interaction between the  
metal structure and the surrounding soil is greatly  
improved. Specifically, according to the invention,  
there is provided a structure in which the metal  
structure is tied to the soil by means of flat bars  
extending horizontally into the stable part of the  
10 granular backfill to a length necessary to anchor  
the structure into the surrounding soil mass by  
frictional interaction between the flat bars  
(strips) and the granular soil. These flat bars are  
preferably made from galvanized steel, although any  
15 other suitable material may be used.

Over the past four decades, soil-metal  
structures have been used successfully in building  
underground conduits of medium and short spans.  
These structures are built with different shapes  
20 (circular pipes, ellipses, pipe arches, and arches)  
and under different ranges of soil cover (shallow to  
deep). They are constructed using corrugated metal  
sheets lapped together using bolted joints to form  
the required shape. Recently, designers have  
25 ventured into using this economic system to replace  
old and deteriorating short-span concrete bridges.  
The economic viability in using them for relatively  
long spans is mainly dependent on the required  
minimum depth of soil cover. Any increase in the  
30 latter will directly affect the costs associated  
with the amount of backfill as well the need for  
longer ramps. For this reason, attempts are made to  
build these structures under the shallowest possible  
depth of cover to improve on the project's economy.  
35 An example of such conditions is the Cheese Factory  
Bridge located in Wellington county in Ontario built



in 1984, with a depth of soil cover of 2.0 m..

Under conditions of long-span and restricted depth of soil cover the surrounding soil may not be able to provide the required support for the conduit. As a result the conduit tends to deform more freely, giving rise to a considerable increase in the bending moment as well as in the susceptibility to sudden buckling failure. Two approaches have been used to deal with the latter problem. One approach is to provide more stiffness to the conduit by attaching stiffeners to the conduit or by introducing relieve slabs over the conduit. However, such an expensive design leads to diverting a larger portion of the vehicular load to the conduit and a smaller portion of the load to the surrounding soil. The second approach is to increase the stiffness of the surrounding soil by cementing the soil, using thrust beams, or by reinforcing the surrounding soil and attaching the conduit into the soil by means of flat bars. This latter approach diverts a greater portion of the vehicular load to the surrounding soil and away from the conduit.

A recent survey has shown that an alarming number of soil-metal structures in Canada, have shown signs of distress such as cracks at bolt holes; buckling and rupture of bottom plates; gross distortion of cross-section including buckling of the top plates; uplift of bottom plates; crimping of ridge corrugations. Actual failures of soil-metal structures have occurred in the past, some of which have been catastrophic in nature involving loss of life. Beside the unfortunate errors in construction, these failures and distress signs can be mainly attributed by and large to the failure of the soil to provide the necessary and expected support to the flexible metal structure.

Failures in soil-metal structures can be of different forms as follows:

5 (a) Crimp Formation: Crimps in the metal structure occur mainly on the valley of the section, extending sometimes to the ridges. Such crimps are caused by excessive bending and/or direct thrust in the metal structure. Also, during manufacturing the bending of the corrugated flat sheets to a small radii as required for haunches of pipe arches, may  
10 also cause such dimples to occur on the interior valleys.

15 (b) Joint Failure: Joint failures in the metal structure occur due to excessive shear or bearing stresses; tearing at bolt holes is then a usual occurrence and rusting of the unprotected torn metal will then accelerate failure of the joint. The seam connection can cause local increase in the bending of the metal structure, or it may create local weakness leading to failure. Thus proper attention  
20 to the seam design is necessary. Poor initial compaction of the soil during construction and unforeseen settlement would also contribute to joint failure.

25 (c) Excessive Deformation: The metal structure can undergo excessive lateral wall displacement which gives rise to excessive vertical deflection at the crown; this causes additional stresses due to bending in the vicinity of the crown. Such a condition is due mainly to poor construction, or due  
30 to the loss of initial compaction at a later stage in the life of the soil-metal structure.

35 (d) Lifting of the Invert of the Metal Structure : This distress results from soil settlement under the haunches of the metal structure; it may be due also to pressure of unexpected water under the metal structure, creating

an uplift on the bottom plates. With adequate cut-off walls, such local failure can be prevented.

The following are the types of overall failures in soil-metal structures:

5           (e) Buckling of the Metal Structure : Buckling  
of the metal structure can sometime lead to  
catastrophic failure. Excessive thrust in the  
structure coupled with excessive deflection around  
the crown can trigger such instability. The  
10 consideration of buckling becomes even more critical  
for longer span structures under shallow cover, as  
well as for structures in the shape of pipe arches  
and horizontal ellipses.

          (f) Soil Failure above the Metal Structure :  
15 Soil-metal structures under shallow cover are  
susceptible to wedge shear failure or tension  
failure in the soil cover. Uneven loading, poor  
compaction of the soil, high flexibility of the  
steel structure all contribute to such soil failure.  
20 Currently, design codes specify minimum depth of  
soil cover in order to avoid such failure.

          (g) Bearing Failure of Soil : The soil pressure  
at the interface between the soil and the metal  
structure tends to be inversely proportional to the  
25 radius of the curvature of the metal structure in  
the form of pipe arches or horizontal ellipses.  
Such soil pressure may exceed the ultimate bearing  
capacity of the soil, thus precipitating failure of  
the surrounding soil.

30           (h) Failure Due to Temperature Effects :  
Temperature variation can have a significant  
influence on the structural performance of soil-  
metal structures. For example, the soil envelope at  
the invert and around the haunches of pipe arches  
35 can become saturated with water and then freeze with  
drop in temperature; this causes increased pressure

on the metal structure as well as displacement in the soil envelope which leads to non-uniform deformation in the metal structure as well as in the surrounding soil. With thawing, an increase in the void ratio in the soil results, i.e. a reduction in the soil density. Cycles of freezing and thawing will then lead to a considerable reduction in the initial compaction of the backfill as well as to higher water seepage and consequently to loss of fine soil particles. Furthermore, with temperature rise, frozen soil containing ice can exert significant pressure against the confining boundaries of the metal structure. Moreover in cold climates ad-freezing (frost grip) forces can be readily activated and this will restrict the freedom of deformation of the metal structure. Variation in the ice content around the metal structure will produce a variation in the ad-freezing forces around the metal structure, thus causing additional strain. The failures at the haunches of the pipe arches can be attributed in large measure to the loss of initial compaction due to the combined action of temperature and seepage effects.

The structural strength and stiffness of soil-metal structures are derived from the full interaction between the surrounding soil and the metal structure; this interaction is created due to the deformation of the metal structure during backfilling. When such interaction is not fully realized due to the poor performance of the soil backfill either during construction or under service loads, problems in the structural response of the metal structure, either from the local failure or complete failure can be expected.

U.S. Patent Nos. 4,610,572 and 4,591,297 describe a method of building a strengthened

embankment by burying horizontal polyethylene nets in the soil mass to provide stability for the future excavation of a semi-cylindrical tunnel. This is basically a method of building a reinforced soil embankment for future tunneling through it, and is not concerned with the placement of a permanent arch or a duct of metal on a base to be thereafter surrounded and covered with backfill.

Canadian Patent No. 1,191,033 discloses an arch-beam structure for use in a metal culvert comprising a pair of concrete or metal wings each extending outwardly from each side of the metal culvert. This is basically a method to distribute the overburden soil pressure acting on the metal culvert and is not concerned with improving the soil properties by providing vertically- and horizontally- distributed layers of low stiffness reinforcing flat bars of negligible beam rigidity, reinforcing the surrounding soil as well as the soil cover.

The differences between Paterson's invention (Canadian patent No. 1,191,033) and the present invention can be summarized as follows:

Present Invention	Paterson's Invention
(a) Pertains to <u>Reinforced-soil</u> metal structures.	Pertains to Soil <u>Reinforced-metal</u> structures.
(b) Uses a number of horizontally- and vertically-spaced layers of reinforcing flat bars having negligible flexural stiffness with considerable axial stiffness.	Uses a pair of wings that are flexurally stiff.



- (c) Provide an option to reinforce the soil cover above the arcuate structure.
- (d) The soil on both sides of the arcuate structure is reinforced with a number of layers of reinforcing flat bars.
- (e) The reinforcing flat bars attached to the sides of the arcuate structure helps in carrying the construction loads throughout the construction stage. The wings attached to the arcuate structure are mobilized only at a much later stage of construction.

5 It is an object of the present invention to improve on the structural response of the soil-metal structure during construction and at the service load stage.

It is another object of the present invention to avoid failures in soil-metal structures by reinforcing the surrounding soil as well as tying the metal structure into the granular soil.

10 It is another object of the present invention to provide a soil-metal structure which adds considerable stiffness to the soil and decreases the movement of the backfill in service such as during freeze-thaw cycles, restrains the movement of the metal structure, and induces large deformations in case of overload, and therefore ample warning before failure.

15 It is another object of the present invention to improve the performance of the soil backfill by reinforcing the soil around and above the metal structure by means of preferably galvanized metallic ties, and tying the metal structure into the surrounding granular soil.

20

It is another object of the present invention to provide a soil-metal arch bridge wherein the soil cover above the arch is reinforced and wherein the arch is tied back by means of soil friction.

5        It is another object of the present invention to provide a structure which prevents snap-through buckling of the arch.

10       It is another object of the present invention to provide soil-metal arch bridge which implies substantial reductions in the axial thrust in the arch.

15       In accordance with the invention, there is provided a soil-metal structure wherein an arcuate self-supporting metallic structure is at least partly covered and surrounded with soil backfill to define an open cavity underneath the soil backfill. The structure comprises at least two vertically spaced-apart layers of soil reinforcing means extending outwardly from each side of the arcuate self-supporting metallic structure, the soil reinforcing means being substantially horizontally disposed and buried in the soil backfill.

20       The arcuate metallic structure may be a buried arch, or a closed conduit of circular, elliptic or pipe arch configuration.

25       In a further construction in accordance with the present invention, the soil reinforcing means includes a plurality of reinforcing flat bars.

30       The arcuate metal structure and the reinforcing flat bars are preferably made of galvanized steel.

35       When the arcuate structure is a buried arch, a concrete footing is preferably mounted in original soil, the buried arch then having both ends disposed in the footing, the reinforcing flat bars being regularly distributed along at least the upper half portion of the arcuate structure..

When the arcuate structure is a closed conduit, a gravel base is preferably provided with the closed conduit sitting on the gravel base. The reinforced flat bars are regularly distributed along the upper  
5 half portion of the closed conduit.

In accordance with a preferred embodiment, a plurality of additional reinforcing flat bars are horizontally disposed and freely embedded in the soil backfill covering the arcuate structure above  
10 the top thereof.

The reinforcing flat bars are preferably tied to the arcuate metallic structure by means of a bracket bolt connection.

For example, such connection may comprise a bracket consisting of a first and a second leg, the  
15 legs forming an obtuse angle between them, a first bolt to attach the first leg of the bracket to the arcuate metallic structure, and a second bolt to attach the second leg of the bracket to the reinforcing flat bar to define the connection.  
20

In a further construction in accordance with the present invention, there is provided a soil-metal structure comprising a self-supporting closed conduit buried in a soil, and at least two  
25 vertically spaced-apart layers of soil reinforcing means extending outwardly from each side of the self-supporting closed conduit, the soil reinforcing means being substantially horizontally disposed and buried in the soil thereby anchoring the self-supporting closed conduit in the soil while at the  
30 same time reinforcing the soil surrounding the closed conduit.

The invention will now be illustrated by means of the enclosed drawings which are given for the purpose of illustration only without any intention  
35 to limit the invention thereto. In the drawing,

Figure 1 is a schematic representation of a soil-metal arch structure according to the invention;

5        Figure 2 is a schematic representation of a soil-metal structure according to the invention wherein the metal structure is a closed conduit of elliptic configuration;

10       Figure 3 is a schematic representation of a soil-metal structure according to the invention wherein the metal structure is a closed conduit of circular configuration;

Figure 4 is a schematic representation of a means of attaching the reinforcing flat bars to a metallic structure.

15       With reference to Figure 1, it will be seen that the soil-metal structure which is illustrated is intended to provide an opening 1 above original soil 3 by means of a self-supporting metallic arch 5 and backfill 7. To support the metallic structure ends 9,11 there are provided footings 13,15 of known construction. The mounting of the arch 5 on the footings 13,15 is of course well known to those skilled in the art. The soil-metal structure illustrated in Figure 1 also comprises a plurality of reinforcing flat bars 17,19 as shown. These flat bars 17,19 are tied at their inner ends to the self-supporting metallic arch 5 in such a way as to be horizontally disposed and buried in the soil backfill 7. The tying of the reinforcing flat bars 17,19 to the self-supporting metallic arch 5 can be executed in any manner well known to those skilled in the art provided the result is a firm, solid and rigid attachment. According to the invention, however, good results have been obtained using the connection illustrated in Figure 4.

35       With reference to Figure 4, it will be seen

that each connection 21 comprises a bracket 23 formed of two legs 25,27, forming an obtuse angle between them. A bolt 29 is used to attach the leg 27 of the bracket 23 to the metal structure 5, while  
5 another bolt 31 which may be similar to bolt 29 is used to attach the leg 25 to the reinforcing flat bar 17. Of course the same arrangement of reinforcing flat bars and their attachment is used on the left half of the structure. As seen in  
10 Figure 1, it is preferable to provide a sufficient number of reinforcing flat bars 17,19 so that they be regularly distributed from the footings 13,15 to the top of the arch 5.

Finally it will be seen in Figure 1 that the  
15 soil-metal structure additionally but not essentially comprises additional reinforcing flat bars 33 which are horizontally disposed and freely embedded in the soil backfill 7 which covers the self-supporting metal arch 5. It has been realized  
20 that the placing of the additional reinforcing flat bars 33 in the soil cover 7 above the crown of the metallic structure, provides a reinforcing-soil deep beam action which further enhances the structural performance of the structure. This beam action  
25 results in considerably reducing the load on the metal structure, and in case of an arch structure 5, reducing the load on the footings 13,15 supporting the arch. Consequently, more load is transferred to the surrounding reinforced-soil mass. Reinforcing  
30 flat bar 33 will have the same cross-sectional area and geometry as reinforcing flat bar 17, 19.

In some cases, it may be preferable to use a closed conduit instead of an arch type metal structure as illustrated in Figure 1. Such conduit  
35 might be elliptic as shown at 32 in Figure 2 , or circular as shown at 35 in Figure 3. In all cases

the same type of reinforcing flat bars 17,19 are used as well as the additional reinforcing flat bars 33. The flat bars 17,19 will be attached to conduits 32 or 35 using the same connection as in Figures 1 and 4. Instead of a footing, the conduits 32,35 are mounted on a gravel base 37, or 39 respectively.

#### COMPARATIVE STUDY

Soil-metal arch structure to carry an OHBDC truck (Ontario Highway Bridge Design Code truck) equivalent to 280 kN with the following characteristics: span of arch = 10.7 m (35 ft); rise of arch = 4.3 m (14 ft); soil cover = 2.1 m (7 ft).

Comparison between traditional design and design according to the invention, in so far as steel used in.

	Traditional design	Invention design
Corrugated section for arch	6 in. x 2 in. x 0.28 in.  (Volume of steel = 1.38 ft <sup>3</sup> /ft.)	2 2/3 in. x 1/2 in. x 0.79 in.  (Volume of steel = 0.32 ft <sup>3</sup> /ft)
Steel flat bars for arch and soil cover	NIL	Volume of steel = 1.15 ft <sup>3</sup> /ft.
Stiffening beams for traditional design	W6 x 15.5 spaced at 2 1/2 ft. (Volume of steel = 0.61 ft <sup>3</sup> /ft)	NIL
Total Volume of steel used	1.99 ft <sup>3</sup> /ft	1.47 ft <sup>3</sup> /ft

Percentage difference =  $1.99 - 1.47 = 34\%$ .  
Thus, according to the invention, savings of some 30% can be realized.

Furthermore, the traditional design, in this case, would require the use of stiffening beams, bent to the shape of the metal arch, and attached to

the arch by means of bolts. This renders the construction very costly, in comparison to the design according to the invention where the flat metal bars are tied in a simple bolted-connection to the metal arch.

5 It has been realized that by reinforcing the soil around and above the metal structure tieing the metal structure into the soil, this will provide stability of the metal structure during  
10 construction; add stiffness to the soil, thus increasing its shear strength; activate the entire reinforced soil medium to assist in the transmission of the load; enhance the arching effect; and, make it possible to observe very large deformations in  
15 the metal structure before its collapse; thus catastrophic failure can be avoided.

The embodiments of the invention in which an exclusive property or privilege is claimed, are defined as follows:

1 - In a soil-metal structure wherein an arcuate self-supporting metallic structure is at least partly covered and surrounded with soil backfill to define an open cavity underneath said soil backfill, the improvement which comprises at least two vertically spaced-apart layers of soil reinforcing means extending outwardly from each side of said arcuate self-supporting metallic structure, said soil reinforcing means being substantially horizontally disposed and buried in said soil backfill.

2 - A soil-metal structure according to claim 1, wherein said arcuate self-supporting metallic structure is a buried arch.

3 - A soil-metal structure according to claim 1, wherein said arcuate self-supporting metallic structure is a closed conduit of circular or elliptic configuration.

4 - A soil-metal structure according to claims 1 to 3, wherein said soil reinforcing means includes a plurality of reinforcing flat bars and wherein said arcuate self-supporting metal structure and said reinforcing flat bars are made of galvanized steel.

5 - A soil-metal structure according to claim 2, which comprises a concrete footing mounted in original soil, said buried arch having both ends disposed in said footing, said soil reinforcing



means being regularly distributed along at least an upper half portion of said buried arch.

6 - A soil-metal structure according to claim 5, wherein said soil reinforcing means are distributed from said footing to a top portion of said buried arch.

7 - A soil-metal structure according to claim 6, wherein said top is the highest point of said arcuate metallic structure.

8 - A soil-metal structure according to claim 3, which comprises a gravel base, said closed conduit sitting on said gravel base, said soil reinforcing means being regularly distributed starting from a spring line to a top of said closed conduit.

9 - A soil-metal structure according to claim 8, wherein said spring line being the locus of the outmost points of the sides of said arcuate self-supporting metallic structure.

10 - A soil-metal structure according to claims 1 to 9, which comprises a plurality of additional soil reinforcing means, said additional soil reinforcing means being substantially horizontally disposed and freely embedded in the soil backfill covering said self-supporting arcuate metallic structure above a top thereof.

11 - A soil-metal structure according to claims 1 to 9, wherein said soil reinforcing means are secured to said arcuate self-supporting metallic structure by means of bracket-bolt connections.

12 - A soil-metal structure according to claim 11, wherein each said connection comprises a bracket consisting of a first and a second leg, said legs forming an angle between them, a first bolt to attach said first leg of said bracket to said arcuate metallic structure, and a second bolt to attach said second leg of said bracket to one of said reinforcing flat bars to define one of said connections.

13 - A soil-metal structure according to claim 4, wherein said reinforcing flat bars have negligible flexural stiffness.

14 - A soil-metal structure according to claims 1 to 13, wherein said arcuate self-supporting metallic structure is at least partly flexible.

15 - A soil-metal structure comprising a self-supporting closed conduit buried in a soil, and at least two vertically spaced-apart layers of soil reinforcing means extending outwardly from each side of said self-supporting closed conduit, said soil reinforcing means being substantially horizontally disposed and buried in said soil thereby anchoring said self-supporting closed conduit in said soil while at the same time reinforcing said soil surrounding said closed conduit.

16 - A soil-metal structure according to claim 15, wherein said soil reinforcing means include a plurality of reinforcing flat bars, and wherein said reinforcing flat bars are at least regularly distributed along an upper half portion of said self-supporting closed conduit.



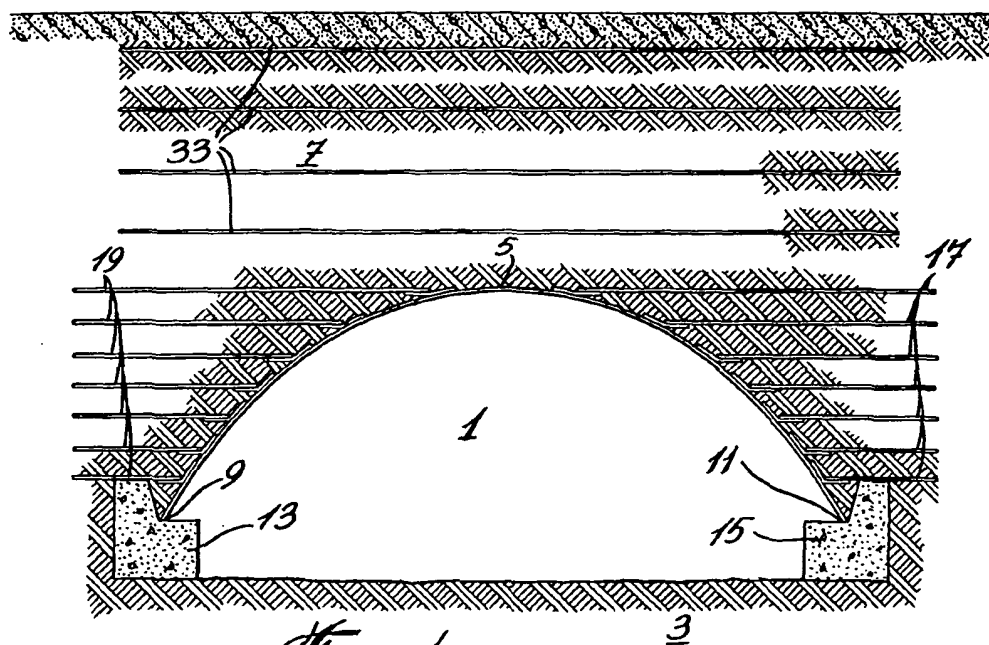


Fig. 1

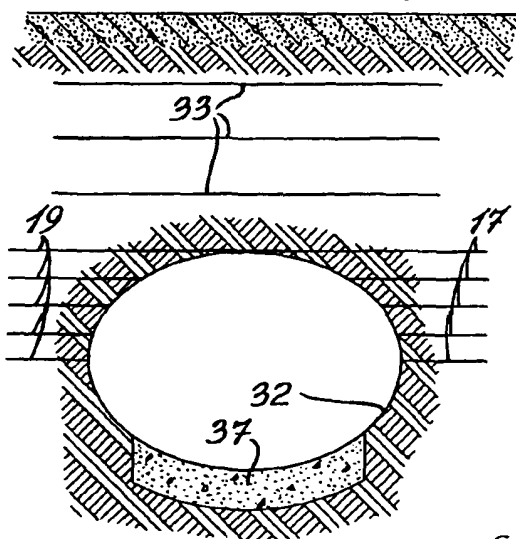


Fig. 2

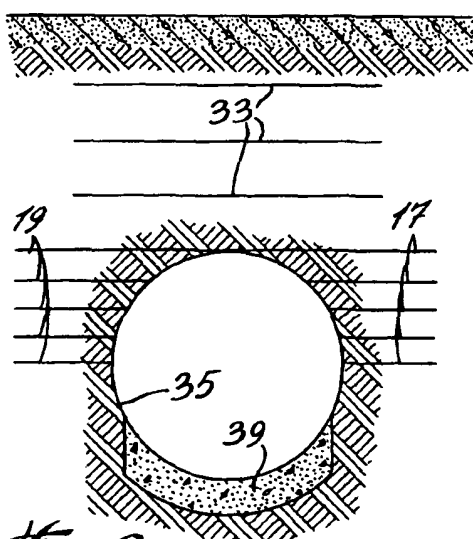


Fig. 3

